1. (6pts) Suppose you have a sample of silicon doped with $10^{17}$ donors/cm$^3$ (i.e. carrier density is $10^{17}$ electrons/cm$^3$). The mobility of electrons in the sample is 1000 cm$^2$/Vsec and the mobility of holes is 300 cm$^2$/Vsec. The minority carrier lifetime is 1 µs. The charge on one electron is 1.6x10$^{-19}$ coul.

a) (2pts) What is the conductivity of the sample?

b) (2pts) Suppose the sample is illuminated in such a way as to create $10^{15}$ electron-hole pairs per cubic centimeter uniformly throughout the sample. What is the relative (%) change in conductivity?

c) (2pts) Suppose at time $t = 0$ the illumination is turned off what will be the approximate hole concentration in the sample after 2 µs. Write the expression you would use to determine the concentration and give an estimate of the value.
2. (7pts) Suppose you have a MOSFET with the characteristic shown, connected in a circuit as shown, with $V_{DD} = 6$ volts.

a) (2pts) What is the approximate transconductance, $g_m$ for $V_{GS} = 4.5V$?

b) (2pts) What is the a DC operating point for $V_{GS} = 4.5V$, i.e. what is the drain current and drain-to-source voltage of the transistor connected as shown? Show the point on the plot.

c) (3pts) Suppose the MOSFET is connected as shown with an AC signal in addition to a DC signal at the input, i.e. $V_{GS} = 4.5V + v_{in}$, where $v_{in} = (0.01V) \sin(2\pi ft)$. What signal would you measure at $v_{out}$?
3. (7pts) Suppose you have a silicon, silicon dioxide, metal sandwich as shown. It is 10 cm long and 1 cm wide. The silicon is 10 µm thick and the silicon dioxide is 1 µm thick. The silicon is n type doped with $10^{17}$ donors per cubic centimeter. The mobility of electrons in the sample is $1000 \text{cm}^2/\text{Vsec}$. The dielectric constant of the oxide is $\varepsilon_{\text{ox}} = 3.5 \times 10^{-13} \text{F/cm}$. You have a battery, resistor and switch connected to one end as shown, and a voltmeter connected at the other end.

a) (2pts) What is the capacitance of the sandwich? And what would be the RC time constant of the circuit given the 60ohm series resistor and the calculated capacitance?

b) (2pts) With this time constant approximately how long after the switch is closed would it take the voltage $V$ across the capacitor to reach $0.9V_B$?

c) (3pts) If the resistance $R = 0$, rather than the than 60 ohms, would the voltage $V$ across the capacitor measured as shown instantly reach $V_B$ after the switch is closed? Discuss the situation qualitatively and quantitatively. (You can use crude models for very approximate, quantitative estimates.)
1. a) \[ \sigma = q \eta \mu_n = 1.6 \times 10^{-19} \text{cm} \cdot 10^{17} \text{cm}^2 \sqrt{\text{Vsec}}, \]
\[ \sigma' = 0.16 \frac{1}{\text{cm}} \]

b) \[ \Delta \sigma = \frac{q}{\eta} (\mu_n \Delta n + \mu_p \Delta p) \]
\[ \Delta n = \Delta p \]
\[ \Delta \sigma = 1.6 \times 10^{-19} \left( 1000 \cdot 10^{15} + 300 \cdot 10^{15} \right) \]
\[ \Delta \sigma = 1.6 \times 10^{-19} \left( 1300 \times 10^{15} \right) \]
\[ \frac{\Delta \sigma}{\sigma} = \frac{(\mu_n \Delta n + \mu_p \Delta p)}{\mu_n \eta} = \frac{1300 \times 10^{15}}{1000 \times 10^{17}} = 0.013 \]

c) \[ \Delta P(t) = \Delta P_0 e^{-\frac{t}{\tau}} \]
\[ \tau = 1 \mu \text{sec} \]
\[ \Delta P(2\mu \text{sec}) = \Delta P_0 e^{-2} = 10^{15} e^{-2} \]

2. a) Transconductance \[ g_m = \frac{dI_C}{dV_C} \]
\[ g_m = 100 \text{ mS} \]
graphically

b) Draw load line from (0, 300 mA) to (6V, 4k)
Operating point \( V_C = 3.5 \text{ V}, I_C = 120 \text{ mA} \).

c) \[ V_{out} = -g m R_2 V_{in} = -0.02 \sin 2\pi t \]
3. a) \[ C = \frac{E_{ox} A}{t_0} = 3.5 \times 10^{-13} \text{F/cm} \times \frac{10 \text{cm}^2}{10^{-4} \text{cm}} \]
\[ C = 3.5 \times 10^{-8} \text{F} \]
\[ RC = (60 \Omega \times 3.5 \times 10^{-8} \text{F}) = 2.1 \times 10^{-6} \text{sec} \]

b) \[ V = V_B(1 - e^{-\frac{t}{RC}}) = 0.9 V_0 \]
\[ (1 - e^{-\frac{t}{RC}}) = 0.9 \]
\[ e^{-\frac{t}{RC}} = 0.1 \]
\[ -\frac{t}{RC} = \ln 0.1 \]
\[ t = -RC \ln 0.1 \]
\[ = -2.70 \mu \text{sec} \ln 0.1 \]

c) For the capacitor to charge completely, current had to flow the entire length \( \frac{\pi}{2} \) the silicon layer. Its resistance is \( R \): \[ R = \frac{1}{\sigma} \]
\[ \sigma = \frac{1}{\eta \mu} = 0.25 \Omega \text{cm} \times 10^{-2} \]
\[ R = \frac{6.25 \times 10^{-2}}{1 \text{cm} \times 1 \times 10^{-3} \text{cm}} = 625 \Omega \]
A crude estimate of charging time can be obtained by dividing the sandwich in half.

\[ \frac{312 \mu F \times 3.5 \times 10^{-8}}{3.5 \times 10^{-8} F} \leq 10 \mu m\]

This is other reasonable way of estimating.